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Colligative Properties

Practical uses of solutions

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Units of Concentration

Whatever units you use, the goal is the same: specify the quantity of 1 component (the solute_s) relative to the quantity of another component (the solvent).

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Common Units

- % by mass
- % by volume
- Mole %
- ppm (parts per million)
- Molarity (M)
- Molality (m)

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Molarity

Molarity is probably the most common unit of concentration in chemistry.

Why is that?

UNITS! UNITS! UNITS!

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Molarity

Molarity (M) = $\frac{\text{moles solute}}{\text{L solution}}$

This is both a chemically relevant unit and a practically relevant unit.

L solution is very easy to measure in the lab!

MOLES! MOLES! MOLES!

Reactions occur based on the relative number of moles.

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% by mass

This is one of the easiest units to use.

Why?

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% by mass

This is one of the easiest units to use.

Why?

UNITS! UNITS! UNITS!

Mass is easy to measure in the lab!

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% by mass

$\% \text{ by mass} = \frac{\text{g solute}}{100 \text{ g solution}}$

This is easy to use, but not as chemically relevant as Molarity. After all, it's all about the MOLES! MOLES! MOLES!

Is this a problem?

Not at all, it is easy to convert these units, but you need to know a few other things.

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Converting M to % by mass

$\% \text{ by mass} = \frac{\text{g solute}}{100 \text{ g solution}}$

$M = \frac{\text{moles solute}}{\text{L solution}}$

What do we need to know to be able to convert from one to the other?

UNITS! UNITS! UNITS! They shall lead the way.

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Converting M to % by mass

Compare the units:

$$\frac{\text{g solute}}{100 \text{ g solution}}$$
$$\frac{\text{Moles solute}}{\text{Liter solution}}$$

What do you see?
Both numerators refer only to solute.
Both denominators refer to the whole solution.
PLEASE! PLEASE! PLEASE! Pay attention to the entire unit - it's not "grams" it's "grams of something"

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Converting M to % by mass

$$\frac{\text{g solute}}{100 \text{ g solution}}$$
$$\frac{\text{Moles solute}}{\text{Liter solution}}$$

If I want to convert the numerators, what do I need to do?

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Converting M to % by mass

$$\frac{\text{g solute}}{100 \text{ g solution}}$$
$$\frac{\text{Moles solute}}{\text{Liter solution}}$$

If I want to convert the numerators, what do I need to do?
(Do I need to say UNITS! UNITS! UNITS! again?)

g solute → moles solute

What's the conversion factor?

$$\frac{\text{g solute}}{\text{moles solute}} \quad \text{Or} \quad \frac{\text{moles solute}}{\text{g solute}}$$

What do we call this?
Molar mass!

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Converting M to % by mass

$$\frac{\text{g solute}}{100 \text{ g solution}} \times \frac{\text{moles solute}}{\text{g solute}} = \frac{\text{moles solute}}{100 \text{ g solution}}$$

Or, if you're going the other way:

$$\frac{\text{moles solute}}{\text{L solution}} \times \frac{\text{g solute}}{\text{moles solute}} = \frac{\text{g solute}}{\text{L solution}}$$

What about the denominator?

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Converting M to % by mass

$$\frac{\text{moles solute}}{100 \text{ g solution}} \times \frac{\text{g solute}}{\text{Liter solution}}$$

100 g solution → L solution

What's the conversion factor?

$$\frac{\text{g solution}}{\text{L solution}} \text{ OR } \frac{\text{L solution}}{\text{g solution}}$$

What's this called?
Density! We need to know the density of the solution and the molar mass of the solute to be able to convert M to % by mass.

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Sample problem

You have a 1.2 M solution of NaCl in water. What is its % by mass given that the density of 1.2 M NaCl is 1.08 g/mL?

What do we do?

Simply convert the units!

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Sample problem

You have a 1.2 M solution of NaCl in water. What is its % by mass given that the density of 1.2 M NaCl is 1.08 g/mL?

$$\frac{1.2 \text{ mol NaCl}}{\text{L solution}} \times \frac{58.453 \text{ g NaCl}}{\text{mol NaCl}} = \frac{70.143 \text{ g NaCl}}{\text{L solution}}$$
$$\frac{70.143 \text{ g NaCl}}{\text{L solution}} \times \frac{1 \text{ L solution}}{1000 \text{ mL solution}} \times \frac{1 \text{ mL solution}}{1.08 \text{ g solution}} = 0.06495 \text{ g NaCl} \cdot 100$$

6.495 g NaCl/100 g solution OR 6.495% by mass
(6.5% by mass to the correct number of sig figs.)

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Slightly more complicated problem

You have a 2.5 M solution of NaCl in water. What is its % by mass given that the density of 1.0 M NaCl is 1.07 g/mL, the density of 3.0 M NaCl is 1.10 g/mL and the density of 5.0 M NaCl is 1.13 g/mL?

This is a more common real-life example. There are tables of solution densities, but they don't have an infinite number of values. So, what do we do...?

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Slightly more complicated problem

You have a 2.5 M solution of NaCl in water. What is its % by mass given that the density of 1.0 M NaCl is 1.07 g/mL, the density of 3.0 M NaCl is 1.10 g/mL and the density of 5.0 M NaCl is 1.13 g/mL?

2 options:
 Use the 3.0 M as being "close enough".
 Do a linear interpolation to determine the approximate value at 2.5 M.

What is a "linear interpolation"?

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Colligative Property

A colligative property is a property that depends ONLY on the amount of the substance present NOT on the identity of the substance.

In other words, it doesn't matter if it is salt, sugar, gasoline, or tennis balls – it will behave the same way!

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Solution

- homogeneous mixtures
 - composition may vary from one sample to another
 - appears to be one substance, though really contains multiple materials
- most homogeneous materials we encounter are actually solutions
 - e.g., air and sea water
- nature has a tendency toward spontaneous mixing
 - generally, uniform mixing is more energetically favorable

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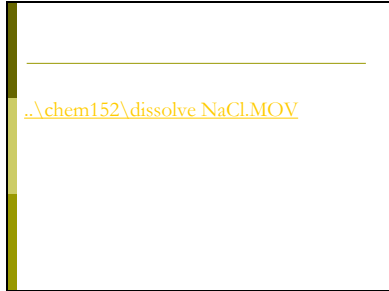
Solutions

□ **solute** is the dissolved substance

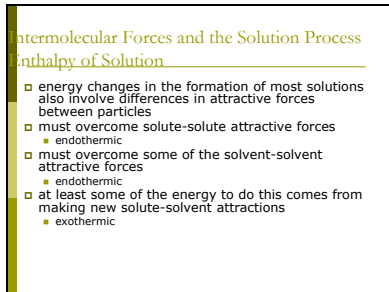


□ solutions in which the solvent is water are called aqueous solutions

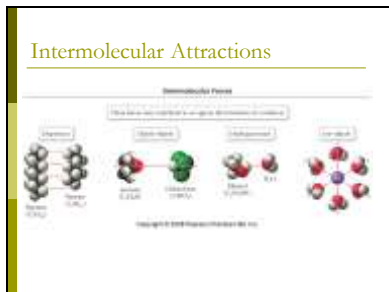
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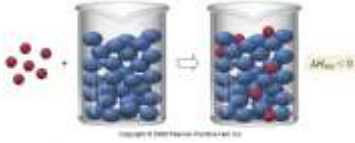


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Solution Process



3. form new solute-solvent attractions, releasing energy
2. add energy in to overcome some solvent-solvent attractions

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Energetics of Solution Formation



if the total energy cost for breaking attractions between particles in the pure solute and pure solvent is **greater than** the energy released in making the new attractions between the solute and solvent, the overall process will be **endothermic**

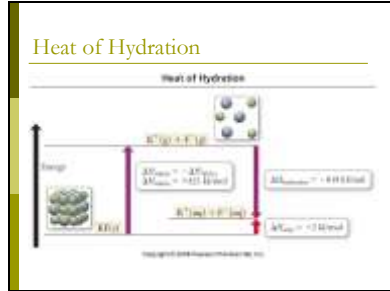
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Heats of Hydration

□ for aqueous ionic solutions, the energy added to overcome the attractions between water molecules and the energy released in forming attractions between the water molecules and ions is combined into a term called the **heat of hydration**

- attractive forces in water = H-bonds
- attractive forces between ion and water = ion-dipole
- $\Delta H_{\text{hydration}}$ = heat released when 1 mole of gaseous ions dissolves in water

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- Some Examples:**
- Vapor Pressure Reduction
 - Related to boiling point
 - Freezing Point Depression
 - Salt on the road
 - Anti-freeze in your radiator
 - Boiling Point Elevation
 - Anti-freeze in your radiator
 - Osmotic Pressure
 - Membrane diffusion
 - The Great Sugar Fountain!

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Vapor Pressure Reduction

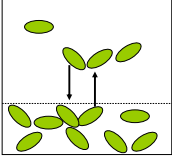
What is "vapor pressure"?

Vapor pressure is the amount (P is proportional to n for ideal gases) of gas A that is in equilibrium above the surface of liquid A.

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Vapor Pressure

At equilibrium, the rate of evaporation (liquid to gas) equals the rate of condensation (gas to liquid). The amount of gas is the "vapor pressure"

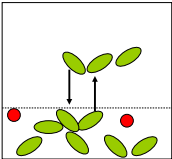


Surface of liquid

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What if you add a solute?

At equilibrium, the rate of evaporation still must equal the rate of condensation. But at any given temperature, the # of solvent molecules at the surface is decreased and, therefore, so is the vapor pressure




Surface of liquid

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Vapor Pressure of Solutions

- the vapor pressure of a solvent above a solution is lower than the vapor pressure of the pure solvent
 - the solute particles replace some of the solvent molecules at the surface

External equilibrium is established when the number of molecules of solvent that leave the liquid surface is equal to the number of molecules that return to the liquid. The vapor pressure will be lower



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NOTE ABOUT THE SIGN CONVENTION

$\Delta T_b = T_{\text{boiling, solution}} - T_{\text{boiling, pure solvent}} = K_b m$

$\Delta T_f = T_{\text{freezing, solution}} - T_{\text{freezing, pure solvent}} = -K_f m$

Δ = change
 Δ = final state - initial state
Many texts do not put a minus sign before the cryoscopic constant and reverse the definition of ΔT_f instead.

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K is a SOLVENT property

Colligative properties don't care what the solute is - they only care how much solute there is.

The boiling point constant and cryoscopic constant are SOLVENT properties only.

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A simple problem

How many grams of sucrose ($C_{12}H_{22}O_{11}$) are needed to lower the freezing point of 100 g of water by 3° C?

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Boiling Point Elevation

What is the "boiling point" of a liquid?

It is the temperature at which the vapor pressure equals the atmospheric pressure. So...

...if you decrease the vapor pressure, you must increase the boiling point – it will take a higher temperature to get enough gas molecules (vapor pressure) to equal the atmospheric pressure.

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What is the Microscopic View of Freezing Point Depression?

These phase change properties arise from the attractive interactions between all molecules (Van der Waal's forces).

When you make a solution, you break some of the solvent-solvent interactions and replace them with solvent-solute interactions.

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Osmotic Pressure

- Osmotic pressure is the "funky" colligative property, but it is very important biologically
- Osmotic pressure is the pressure required to overcome the natural pressure exerted by a solution by virtue of having a concentration.
- Osmotic pressure looks just like the ideal gas law:
 $\Pi V = nRT$
where Π is osmotic pressure
 $\Pi = (n/V) RT = M RT$

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Why is it important?

Consider two solutions separated by a semi-permeable membrane (meaning water can pass through but nothing else) at room temperature (298 K).

On one side of the membrane is a 1 M NaCl solution. On the other side is a 4 M NaCl solution.

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What Happens?



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It's all about sweating!

- What happens when you sweat?

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It's all about sweating!

What happens when you sweat?

Your body loses water and some dissolved salts through your skin which cools your body.

What is the price you pay for this?

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The cost of sweating

Your cells have lost precious water and salts.

What do you do about it?

Drink water?

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